TRANSPORTATION ENGINEERING

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Summary

As transportation problems become increasingly complex structurally, a balanced mix of transportation modes is essential. Appropriate countermeasures are needed not only at the stage of traffic planning but also in traffic management. Therefore, transportation engineering should cover a wide spectrum of areas including railways, aviation, water transportation, pipelines, etc., besides highway traffic engineering.

It can be said in plain terms that the subject of transportation engineering is concerned with appropriate knowledge and technology aimed at the best usage of transportation facilities and systems. Usually in the actual field of road traffic for example, it is considerably difficult to find and apply the best set of measures, since there are complex evaluation viewpoints of various users for the design of the transportation systems.

This chapter provides an overview of the fundamentals of planning, design, control, and management aspects of surface transportation, and among various fields, road transportation is mainly explained considering both the complicated structure of revealed problems and many combinations of countermeasures to alleviate the problems. In each part, some selected typical and essential features are described in some detail among many relevant items in each field.

1. Introduction

According to the U.S. Institute of Traffic Engineering, established in 1930, traffic engineering :" is the field which handles the highway planning, geometric designs, traffic operation and management, highway networks, terminals, land use of neighboring sites and the relations with other means of traffic, in order to achieve the safe, efficient and convenient movement of the human-beings and the goods." Thus, the definition focused mainly on the vehicular traffic. This organization changed its name to "Institute of Transportation Engineering (ITE)" in 1978 and has been attempting to reform and widen the range of subjects to tackle. There seems to exist some of the following changes of the situation in the background: the transportation problems become structurally more and more complex and therefore a balanced mix of transportation modes is essential.

Furthermore appropriate countermeasures are needed not only at the stage of traffic planning but also in traffic management. Accordingly transportation engineering should cover a wide spectrum of areas including railways, aviation, water transportation, pipelines, etc., besides highway traffic engineering. In other words, an integrated system of transportation facilities is necessary for the solution of the transportation problems, and an efficient system of updating knowledge and experience is essential.

It can be said in plain terms that the subject of transportation engineering is concerned with appropriate knowledge and technology aimed at the best usage of transportation facilities and systems. In the context of highway traffic engineering, "the best" usage implies not only ensuring safe, smooth and comfortable conditions for all road users including vehicles, bicycles and pedestrians, but also providing the benefits which the roads naturally bring to the roadside inhabitants and land use with the minimum negative influences such as pollution due to the existence of roads.

Usually in the actual field of the road traffic, it is considerably difficult to find and apply the best set of measures, since there are complex evaluation viewpoints of various users for the design of the transportation systems and the mutually exclusive evaluation items to be achieved. Even under such conditions, the knowledge of what kind of measures can respectively have the definite effects must be prepared systematically, concerning the aspects of efficiency, safety, amenity and environmental preservation, from the standpoints of the transportation engineers.

Transportation engineering, as mentioned above, covers a very wide set of areas and thus an appropriate understanding of each field should be requisite. However sufficient description of all the fields may not be possible in this chapter due to space limitation. Therefore, the main descriptions are focused on the road transportation as a representative of surface transportation.

The reasons for taking up road transportation especially among various fields, are as follows: firstly, there are specific characteristics such as different structures of the problems which are associated with different backgrounds, for example, locations to be discussed, problems to be solved and measures are greatly different by the combination of transportation facilities, systems, and regulations applied. Secondly, more complicated counters are needed than in other fields and more considerations for various aspects seem to be necessary, since correspondent subjects for problems are many and the viewpoints for the transportation system evaluation are also different respectively for the problems to be treated.

Among various problems, traffic jams, traffic accidents and traffic pollution are the three most serious problems to be tackled in the fields of road traffic and the continuous execution of countermeasures for relieving problems is required urgently. In this chapter, the prevailing knowledge concerning these issues in transportation engineering is to be introduced and some new recent challenges and movements are summarized.

This chapter is composed of the following five parts considering the major fields applied in transportation engineering. In each part, limited typical and essential features are selected for explanation in some detail among many relevant items in each field.

The first is the fundamental field which deepens our understanding and recognition of traffic phenomena or various characteristics in transportation engineering. It is important to know various features of the components of the road transportation and the characteristics concerning a traffic flow such as vehicles, two-wheeled vehicles, pedestrians, because this kind of information becomes the basis in all sides of transportation engineering. These include characteristics of traffic flows, traffic flow models, traffic capacity -the basic information in the operation, and the fundamental mechanisms of the generation of traffic jams, etc.

The second is the field of transportation planning. In this field, the following are explained: the framework of the plan, the procedures of traffic planning, traffic demand prediction techniques, the planning of the public transportation system, and investigations for traffic planning, etc. In recent years, these have been the subjects of intense research.

The third is the field of road design, which examines the relationships between the structures /facilities, and the road safety, the traffic smoothness and the environmental aspects. Knowledge gained through every research activity and experiment of transportation engineering is utilized for the improvement of road and transportation facility effectively, and the construction criterion of the road facilities.

The fourth is the practical field that is concerned with traffic management and operation of highway facilities. It includes traffic signalization, traffic regulations (one-way operation, parking regulation, etc.), location of roadway space (lanes, intersection channelizations, etc.), improvements of bus operations (bus-lanes, bus location systems) and so on. The following components are applied in these systems: Traffic signs and variable-message signs, road lighting, comprehensive traffic control systems integrating these elements efficiently, etc. This is the actual field of transportation engineering, so to speak.

The fifth part is the field of highway safety. Procedures of highway safety programs are introduced and the fundamentals in each step are explained for the efficient execution of the accident preventive measures.

2. Traffic Flow Fundamentals

2.1 Traffic Flow Characteristics and Theory

2.1.1 Time-Space Diagram

The time-space diagram has been well used by traffic engineers to analyze vehicle motions. The vertical and horizontal axes respectively show space (distance) and time. A vehicle motion can be therefore drawn as a trajectory on this two-dimensional diagram. The slope of a trajectory with reference to the time axis indicates the speed of the concerned vehicle, the horizontal distance between two adjacent trajectories shows the headway of the vehicles and the vertical interval of the trajectories gives the spacing. Since the inverse of headway is flow and the inverse of spacing is density, dynamic change of flow, density, and speed can be explained from the time-space diagram.

2.1.2 Flow-Density-Speed Relationship

Flow is defined as the number of vehicles passing at a certain location per unit time. Density is defined as the number of vehicles at a certain time per unit distance. Speed (space mean speed) is defined as flow divided by density. These three are key variables to analyze traffic flow in traffic engineering. Since a universal relationship among the three variables, flow = (space mean) speed $\times$ density, is maintained, one is determined from the other two variables.

Empirical observations show that speed decreases as density increases. In particular, Greenshields reported a linear relationship between speed and density. If the linear relationship is combined with the above universal relationship, relationships between any two of the three variables can be obtained. For instance, from Greenshields' model, flow becomes a quadratic function of density and also quadratic function of speed. There have been quite a few empirical observations that reported slightly different relationships, although the general tendencies among the three variables are the same.

2.1.3 Queuing Theory

Queuing theory is another useful tool to evaluate mainly vehicle delay. Conventionally, we draw the cumulative number of vehicles passing a certain location. The cumulative figure shows time-dependent vehicle passing time at the particular location. In order to evaluate delay on a section from location A to B, the cumulative curves at locations A and B are useful. Then, the area between two cumulative curves shows total delay on the section for a specified time period. If FIFO (First In First Out) discipline is assumed for all the vehicles passing the section, individual vehicle delay can be evaluated as the horizontal time period between two curves. Note that, under FIFO, a vehicle passing location A earlier than another one is assumed to also pass location B earlier.

The analysis using the cumulative figures is called as the deterministic queuing theory, since stochastic fluctuations of vehicle passing times are not explicitly considered. For traffic phenomena with a huge queue, stochastic effect on the delay may not dominant and therefore the deterministic theory is sufficient. And also, since the deterministic analysis is basically based upon only vehicle input and output from the study section but independent of vehicle motions on the section, the deterministic theory seems robust to evaluate delay. However, most of the deterministic queuing theories employ point queues that have no physical lengths. Thus, you cannot evaluate queue backing up phenomena from the point queue analysis. Recent studies however combine the deterministic queuing theory with the kinematic wave theory to evaluate queue backing up.

On the other hand, for phenomena not always with a queue such as traffic at an undersaturated intersection where a queue forms during red but vanishes by the end of green, stochastic effect on delay my not be negligible. Especially, the stochastic effects become dominant for near saturated condition. In stochastic queuing theory, one has to define stochastic passing time distribution. For example, at an intersection, traffic engineers have frequently used Poisson arrivals and uniform departures to evaluate queuing delay stochastically.

2.1.4 Kinematic-Wave Theory

The kinematic-wave theory was developed in 1950s mainly by physicists. They applied the theory of wave motion to traffic flow. The theory explains motions of forward and backward wave along one-dimensional flow stream. A collision of forward and backward waves is known as a shock that can be physically seen as a boundary of different traffic conditions. For instance, the tail of a queue is one kind of shock because upstream of the tail is free flow condition and its downstream is congested flow condition. From the theory, in particular, hence we can explain the motion of forward and backward queue propagation.

The theory was constructed based upon the flow conservation principle on a highway section and the flow-density-speed relationship. Assuming that flow is explained by density, the wave is defined as the partial derivative of flow with respect to density: a slope of the flow-density relationship. Then, we can obtain an important property that flow rate does not change on the trajectory of the wave, which is called the characteristic curve. This means, for example, when a queue starts growing on a highway section, a contour line of the same flow rate at the downstream end of the section can be found along the backward wave trajectory.

The kinematic-wave theory was recently combined with the deterministic queuing theory. This extended theory explains shock-wave propagation from cumulative curves and flow-density relationship mentioned above.

2.1.5 Car-Following Theory

The car-following theory explains the longitudinal motion of an individual vehicle responding to the motion of its leader. The theory was originally developed also in

1950s and has been modified in various ways. The simplest form of the car-following model assumes that the vehicle acceleration with time lag is proportional to the relative speed with respect to its leader. The constant coefficient of the linear car-following model is called the sensitivity. The sensitivity is however sometimes assumed as a function of its speed and the spacing from the leader.

The linear car-following model and its family were well analyzed because of its simple form and the mathematical elegance. Local as well as asymptotic instabilities of change in spacing and derivation of the flow-density-speed relationship are examples of the analysis. However, since the ability to describe real vehicle motion is limited, several more complex models have been reported.

2.1.6 Traffic Simulation

Traffic simulation is a tool, which reproduces complex real traffic phenomena by combining relatively simple traffic models and user behavioral models. Due to the sophisticated computer technology, various traffic simulation models have been developed since the late 1970s. Traffic simulation models cover wide range in terms of the size of study area. Generally speaking, a model focusing on small areas such as a few intersections employs a detailed flow model which reproduces not only longitudinal but lateral vehicle motions such as lane changing, overtaking, etc. On the other hand, models considering thousands of links and nodes have been also developed but based upon simpler vehicle models.

Although traffic simulation is a useful tool to describe complex phenomena of a specific situation, it would be difficult to extract general consequences of cause and effect relationship. Also, since simulation models are usually combinations of many simple models, most users tend to have difficulty to understand the abilities and applicability of simulation models.

2.2 Traffic Capacity

2.2.1 Simple Section

Traffic capacity of a simple straight pipe section is classified into three categories. The basic capacity is traffic capacity under ideal conditions such as sufficient lane width and lateral clearance, good alignment, passenger cars only, and no speed limit. While the basic capacity of a multi-lane highway is defined as the number of passenger cars being able to pass per unit time for one lane, one for a two-lane highway is defined for two lanes together, since traffic capacity on one direction is influenced by traffic in the opposite direction.

The possible capacity is capacity modified based upon actual traffic condition and geometric design. The design capacity is furthermore modified taking the level of service into consideration.

2.2.2 Merging, Diverging, Weaving Sections

Traffic capacities at merging, diverging, and weaving sections are more difficult to explain than one for a simple section because of the complicated geometric design as well as flow streams. For merging and diverging capacities, at least two flow streams must be considered. And since weaving is merging followed by diverging, four different streams must be considered. Moreover, their geometric designs are more complicated depending upon angle of merging and diverging, types of weaving, etc. Thus, an internationally well accepted method to estimate such capacities from traffic condition and the geometric design has not been developed, although historical experimental results have been summarized in capacity manuals.

2.2.3 Intersections

Intersections are classified into two: unsignalized and signalized intersections. For unsignalized intersections, the capacity must be estimated based upon the traffic regulation such as stop and yield control. Experimental results have been summarized in manuals. For signalized intersections, the signal control must be considered. In general, for both types, the capacity analysis for a simple section is modified based upon intersection control mentioned above.

2.3 Sensing Technology and Surveillance

2.3.1 Sensors

Conventional traffic detectors have mainly two types: an ultrasonic detector and an inductive loop detector. An ultrasonic detector is installed above a road surface and measures a round trip travel time of ultrasonic signal between the detector and an object underneath, while a loop detector is installed under the pavement and measures inductive impedance. These sensors can measure flow and time occupancy. If the sensors are installed as a pair, vehicle speed can be also measured. Recently, an ultrasonic detector, which identifies vehicle type based upon measured vehicle height, has been developed.

An image sensor detects vehicles from their monitored images. Images obtained from video cameras are processed to automatically estimate flow, speed, and vehicle types. Some types of sensors can find out a queue length.

Beacon has two types: infrared and microwave beacons. Similar to the conventional detectors, both beacons measure flow and occupancy. But, an infrared beacon has not only sensing but also communication functions. If a vehicle carries on-board equipment, an infrared beacon can communicate with the vehicle. It receives the randomized vehicle ID, the previous beacon ID, and travel time from the previous beacon passed, while it transmits traffic information to the vehicle. Because of the communication, the infrared beacon identifies individual vehicle and hence a trip route of the vehicle is observed.

2.3.2 Surveillance

Traffic surveillance is composed of various functions. Road maintenance and road surface monitoring have been carried out from sensors as well as highway patrols.

Weather monitoring utilizing various sensors such as rain, fog, snow, and wind gauges is another important function.

To understand current traffic condition, sensing data are analyzed so as to estimate real-time traffic flow, density, and speed at key highway sites. Also, these data have been used to detect incidents such as traffic accidents and vehicle malfunctions.

The Dedicated Short Range Communication system developed recently can identify individual vehicles traveling on highways. The communication with vehicles through infrared beacons and automatic toll transaction systems through ETC (Electronic Toll Collection) are already realized technology of DSRC. Data obtained by these recent tools reveal routes, origin-destinations, intersection-turning movements, which would be utilized for traffic surveillance as well as for transportation planning.

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